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DIELECTRIC COMPOSITION AND INTEGRATED CIRCUIT DEVICE

Field of the Invention

The present invention relates to an improved dielectric composition and to an integrated circuit comprising the improved dielectric material.

Background of the Invention

Polyimides are known in the art for use in the manufacture of integrated circuits including chips (e.g., chip back end of line), thin film packages, and printed circuit boards. Polyimides are useful in forming dielectric interlayers, passivation layers, alpha particle barriers, and stress buffers. Polyimides are particularly useful as an interlayer dielectric material to insulate the conductor wiring interconnecting the chips on a multichip module. This is known as thin film wiring. A multichip module is an intermediate level of packaging between the chips and the circuit board. Multichip modules are generally known in the art. Multichip modules are made up of multiple layers of power, signal, and ground planes which deliver power to the chips and distribute the input/output signals between chips on the module or to/from the circuit board.

There is a continuing desire in the microelectronics industry to increase the circuit density in multilevel integrated circuit devices, e.g., memory and logic, thereby increasing their performance and reducing their cost. In order to accomplish this goal, there is a desire to reduce the minimum feature size, e.g.,

circuit linewidth, and also to decrease the dielectric constant of the interposed dielectric material to enable closer spacing of circuit lines without increase in crosstalk and capacitive coupling. Polyimide has a dielectric constant of about 3.0 with mechanical and thermal properties to withstand present processing operations and thermal cycling associated with semiconductor manufacturing. However, it is desired that dielectric materials for future integrated circuit devices exhibit a lower dielectric constant (e.g., < 3.0) than exhibited by polyimide and have improved mechanical and thermal properties.

It is therefore an object of the present invention to provide an improved integrated circuit device comprising an improved dielectric material.

Other objects and advantages will be apparent from the following disclosure.

Summary of the Invention

The present invention relates to an improved dielectric material comprising cured polyamic ester terminated preferably with a trialkoxysilylalkyl group. The present invention also relates to an integrated circuit device. In one embodiment the devices comprises (i) a substrate, (ii) interconnecting metallic circuit lines positioned on the substrate, and (iii) the improved dielectric material positioned contiguous to the circuit lines (over and/or between the circuit lines).

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The present invention also relates to an integrated circuit packaging device and processes for forming the integrated circuit devices of the present invention.

A more through disclosure of the present invention is presented in the detailed description which follows and from the accompanying drawings.

Brief Description of the Drawings

Fig. 1 is a cross-sectional view of a portion of an integrated circuit device of the present invention.

Figs. 2-5 show a process for making an integrated circuit device of the present invention.

Figs. 6-8 show an alternative process for making an integrated circuit device of the present invention.

Detailed Description of the Invention

An embodiment of the integrated circuit device of the present invention is shown in Fig. 1. The device generally comprises substrate 2, metallic circuit lines 4, and the improved dielectric material 6 of the present invention. The substrate 2 has vertical metallic studs 8 formed therein. The circuit lines function to distribute electrical signals in the device and to provide power input to and signal output from the device. Suitable integrated circuit devices will

generally comprise multiple layers of circuit lines which are interconnected by vertical metallic studs.

Suitable substrates for the device of the present invention comprise silicon, silicon dioxide, glass, silicon nitride, ceramics, aluminum, copper, and gallium arsenide. Other suitable substrates will be known to those skilled in the art. In a multilayer integrated circuit device, an underlying layer of insulated, circuit lines can also function as a substrate.

Suitable circuit lines generally comprise a metallic, electrically-conductive material such as copper, aluminum, tungsten, gold, silver, or alloys thereof. Optionally, the circuit lines may be coated with a metallic liner such as a layer of nickel, tantalum, or chromium, or other layers such as barrier or adhesion layers (e.g., SiN, TiN).

A preferred embodiment of the present invention relates to an integrated circuit packaging device (multichip module) for providing signal and power current to a one or more integrated circuit chips comprising: (i) a substrate having electrical conductor for connection to a circuit board, (ii) a plurality of alternating electrically insulating and conducting layers positioned on the substrate wherein at least of the conducting layers comprises the improved polyimide film of the present invention and (iii) a plurality of vias for electrically interconnecting electrical conductor, conducting layers and integrated circuit chips.

The integrated circuit packaging device is an intermediate level of packaging between the integrated circuit chip and the circuit board. The integrated circuit chips are mounted on the integrated circuit packaging device which is in turn mounted on the circuit board.

The substrate of the packaging device is generally an inert substrate such as glass, silicon or ceramic. The substrate can optionally have integrated circuits disposed therein. The substrate is provided with electrical conductor such as input/output pins (I/O pins) for electrically connecting the packaging device to the circuit board. A plurality of electrically insulating and electrically conducting layers (layers having conductive circuits disposed in an dielectric insulating material) are alternatively stacked up on the substrate. The layers are generally formed on the substrate in a layer by layer process wherein each layer is formed in a separate process step.

The packaging device also comprises receiving means for receiving the integrated circuit chips. Suitable receiving means include pinboards for receipt of chip I/O pins or metal pads for solder connection to the chip. Generally, the packaging device also comprises a plurality of electrical vias generally vertically aligned to electrically interconnect the I/O pins, the conductive layers and integrated circuit chips disposed in the receiving means. The function structure and method of manufacture of the integrated circuit packaging devices are well known to those skilled in the art as disclosed in U.S. Patent Nos. 4,489,364,

4,508,981, 4,628,411 and 4,811,082, the disclosures of which are incorporated herein by reference.

The key feature of the present invention is the dielectric material which is positioned over, around and/or between the circuit lines. In multilevel integrated circuit devices, the dielectric material can be often planarized to function as a substrate for the formation of the next layer of circuit lines. The dielectric material comprises an imidized polyamic ester terminated (end group) with $(RO)_m(R'')_nSiR'$-, where , m is 1, 2 or 3; m+n=3; R and R′ are hydrocarbyl groups and R″ is hydrido or a hydrocarbyl group. The end group is preferably a mono, di or tri C_{1-6} alkoxysilyl C_{1-6} alkyl or aryl group (e.g., phenylene, benzylene, napthylene or anthracenylene) group. As used herein, hydrocarbyl group means hydrocarbon based group (mono or difunctional) having a carbon atom attached to the remainder of the molecule and having predominantly hydrocarbon character. Hydrocarbyl groups include the following:

(1) Hydrocarbon groups; that is, aliphatic, (e.g., C_1-C_{10} alkyl or alkenyl and C_{5-10} cycloalkyl or cycloalkenyl), aromatic, aliphatic substituted aromatic, aromatic-substituted aliphatic and the like. Such groups are known to those skilled in the art; examples include methyl (methylene for difunctional hydrocarbyl group) ethyl, butyl, hexyl, octyl, decyl, dodecyl, tetradecyl,

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octadecyl, cyclohexyl, phenyl, naphthyl, benzyl and anthracenyl (all isomers being included).

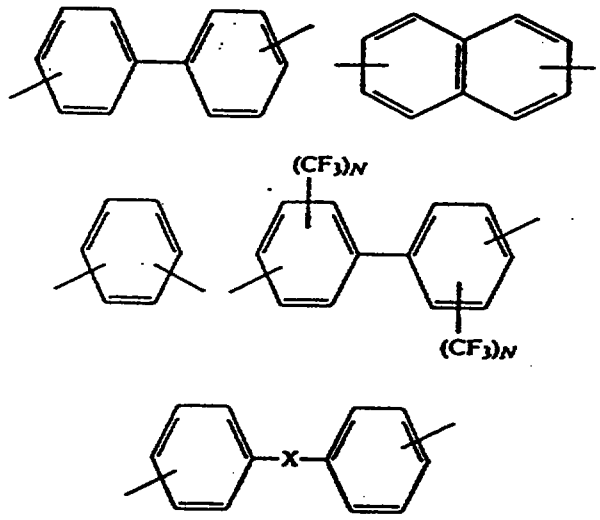
(2) Substituted hydrocarbon groups; that is, groups containing non-hydrocarbon substituents which, in the context of this invention, do not alter predominantly hydrocarbon character of the group. Those skilled in the art will be aware of suitable substituents (e.g., halo, alkoxy, carbalkoxy, nitro).

(3) Hetero groups; that is, groups which, while predominantly hydrocarbon in character within the context of this invention, contain atoms other than carbon present in a chain or ring otherwise composed of carbon atoms. Suitable hetero atoms will be apparent to those skilled in the art and include, for example, nitrogen, oxygen and sulfur.

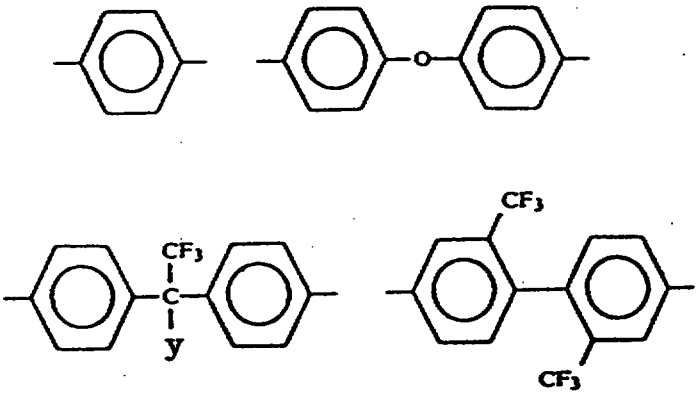
In general, no more than about three substituents or hetero atoms, and preferably no more than one, will be present for each 10 carbon atoms in the hydrocarbon-based group.

The polyamic ester with the end group is preferably formed from the reaction of (i) a diamine; (ii) a diester diacyl halide (e.g., chloride) and (iii) an aminoalkoxysilane.

Suitable diamines have the formula H_2NRNH_2 wherein R is



wherein X is selected from the group consisting of an alkylene chain having 1-3 carbon or halocarbon atoms, carbonyl, —O—, —S—, —SO_2— and —N— alkyl. The alkylene chain can further be substituted with haloalkyl (e.g., trifluoromethyl) and phenyl. The aromatic ring can optionally be substituted by a e.g., trifluoromethoxy or the like. Suitable R for the diamine include:



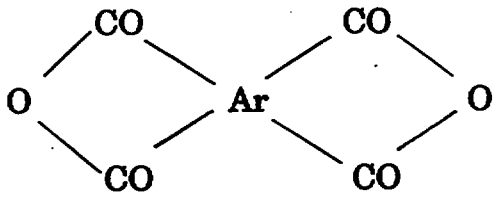
where y is selected from trifluoromethyl, phenyl or substituted phenyl. Suitable aromatic diamines are:

p-phenylene diamine;
4,4'-diamino-diphenylamine; benzidine;
4,4'-diamino-diphenyl ether;
1,5-diamino-naphthalene;
3,3'-dimethyl-4,4'diamino-biphenyl;
3,3'-dimethoxy benzidine;
1,4-bis(p-aminophenoxy) benzene;
1,3-bis(p-aminophenoxy) benzene;
2,2-bis[4-aminophenyl] hexafluoropropane

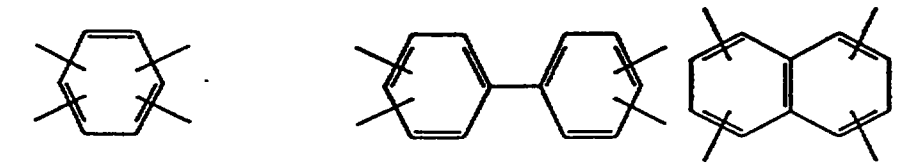
The R in the diamine may also be an aliphatic or cycloaliphatic group such as cycloalkylene e.g., cyclohexylene. Suitable aliphatic diamines include 1,4-diaminocyclohexane and bis (4-aminocyclohexyl) methane.

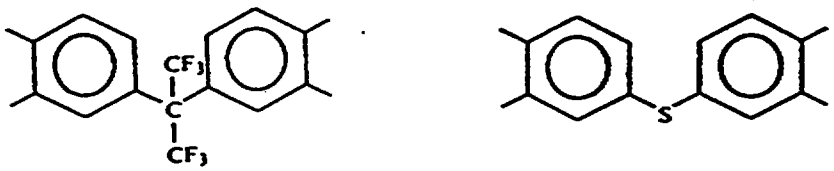
A preferred diamine is a diamine wherein X in the above formula is >C (phenyl) (trifluoromethyl). Preferred diamines are 9,9′-bis (4-aminophenyl) fluorene (FDA); 4,4′-oxydianiline and 1,1-bis (4-aminophenyl)-1-phenyl-2,2,2-trifluoroethane (3FDA).

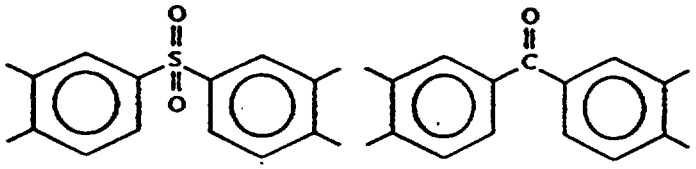
The diester diacyl chloride is suitably made from the corresponding dianhydride suitably having the formula

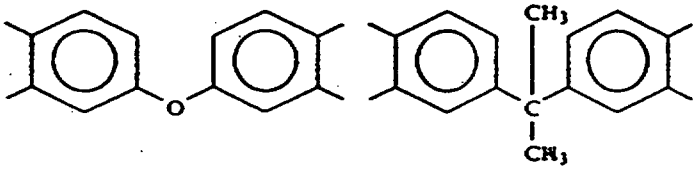


wherein Ar may be selected from.









Suitable dianhydrides include:

pyromellitic dianhydride
benzophenone dianhydride
2,2-bis(3,4-dicarboxyphenyl) propane dianhydride
3,3',4,4'-biphenyltetracarboxylic acid dianhydride
bis(3,4-dicarboxyphenyl) ether dianydride
bis(3,4-dicarboxyphenyl) thioether dianhydride
bisphenol A bisether dianhydride
2,2-bis(3,4-dicarboxylphenyl)hexafluoropropane dianhydride
2,3,6,7-naphthalenetetracarboxylic acid dianhydride
bis(3,4-dicarboxyphenyl) sulfone dianhydride
1,2,5,6-naphthalene tetracarboxylic dianhydride;
2,2',3,3'-biphenyl tetracarboxylic dianhydride
3,4,3'4' benzophenone tetracarboxylic dianhydride; and
terphenyldianhydride

A preferred diester diacyl chloride is diethyl pyromellitate diacyl chloride.

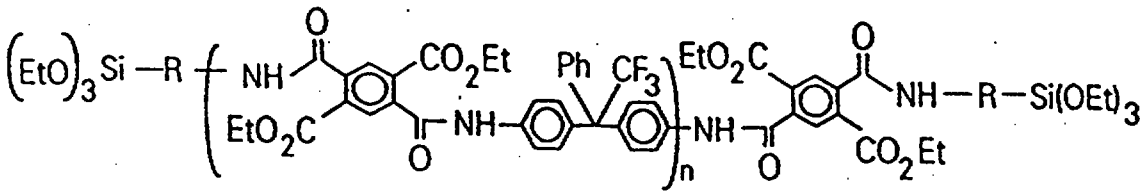
The diester diacyl chloride is formed by sequentially reacting the corresponding anhydride with a suitable alcohol and oxalyl chloride. A suitable alcohol is ethanol. The rate of imidization can be varied by the electronic substituent effect of the ester group (e.g., ethyl ester substituent from ethanol) and other suitable alcohols for use in the present invention will be known to those skilled in the art such as disclosed on page 139 of "High Performance Polymers" by Hergenrother (1994), the disclosure of which is incorporated herein by reference. Suitable diester diacyl chlorides are diethyldichloro-pyromellitate, diethyl dichlorobiphenyl tetracarboxylate and diethyldichloro oxydiphthalate. Other suitable diamines and diester diacyl chlorides will be

known to those skilled in the art such as those disclosed in U.S. Patent 4,720,539 and copending commonly assigned U.S. Patent Application Serial No. 08/058,303 filed May 10, 1992, the disclosures of which are incorporated herein by reference for all purposes.

Suitable aminoalkoxysilane has the formula $(H_2NR'Si(R'')_m(OR)_n)$ where m+n=3 (n is preferably 3) R is preferably C_{1-6} alkyl and R′ is a spacer group preferably a C_{1-6} alkylene (e.g., methylene) or a nonheteroatom aryl group (a hydrocarbon aromatic group without heteroatoms) such as phenylene, benzylene or napthylene) which is positioned between the amino group and the silicon atom. Since R is cleaved and removed from the composition during the reaction, R can be any organic group which does not unacceptably interfere with the reaction and those groups should be contemplated as equivalent to those claimed herein. If n is less than 3, R″ is preferably hydrido or lower C_{1-6} alkyl. A preferred silane is aminophenyltrimethoxysilane. Other suitable silane reactants will be known to those skilled in the art.

To form the polyamic ester reactant, the three precursors are dissolved in a suitable solvent (such as NMP) in proper stoichiometric amounts (e.g., diamine and diester diacyl chloride in 1:1 with the amount of silane calculated from the Carothers equation to provide the desired molecular weight of the polymer product) resulting in alkoxy silylalkyl end capping of the polyamic ester. The alkoxysilylalkyl end capped polyamic ester reactant will have a

molecular weight (Mn) of about 5,000 to 20,000 g/mol. A suitable alkoxysilylalkyl end capped polyamic ester has the structure:



wherein R is phenyl or C_{1-6} alkyl and the polyamic ester substituent is ethyl.

The polyamic ester can be isolated and purified if desired. The polyamic ester solution has a high solids content (e.g., > 40-50 wt. %) with a low viscosity. The polyamic ester can be disposed on a substrate as a film by standard art-known techniques.

The dielectric composition is formed by curing the polyamic ester. The polyamic ester has a high imidization temperature of greater than 375°C. To cure the composition, the composition is heated to an elevated temperature directly or in a stepwise fashion (e.g., 200°C for 2 hrs. to cause chain extension and then ramped up to 400°C and held for 2 hrs.) to cause complete imidization of the polyamic ester and cross condensation of the silyl reactive groups.

The dielectric composition of the present invention has a dielectric constant less than 3.2, preferably less than 3.0, and more preferably less than 2.8 at 80°C. The dielectric composition has a low thermal expansion coefficient at elevated temperatures (e.g., less than 1000 x 10^{-6} [i.e., 1000 ppm] at 450°C preferably less than 500 x 10^{-6}; more preferably less than 100 x 10^{-6}) to

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avoid film cracking during subsequent thermal process steps. The composition has enhanced mechanical and polishing characteristics and enhanced isotropic optical and dielectric properties. The composition also has thermal stress of less than 100 MPa, preferably less than 50 MPa. Further, the dielectric composition has mechanical properties that resist cracking and enable it to be chemically/mechanically planarized to facilitate lithographic formation of additional circuit levels in multilevel integrated circuit devices. The dielectric composition has increased breakdown voltage, enhanced toughness, and increased crack resistance, even in high ambient humidity with a thick film. The dielectric composition is optically clear and adheres well to the substrate. The dielectric composition undergoes minimal shrinkage during heating (e.g., less than 10%).

The present invention also relates to processes for manufacturing the integrated circuit device. Referring to Fig. 2, the first step of one process embodiment involves disposing on a substrate 2 a layer 10 of the dielectric composition of the present invention comprising trialkoxysilylalkyl end-capped polyamic ester. The substrate 2 is shown with vertical metallic studs 8. The polyamic ester is dissolved in a suitable solvent such as dimethyl propylene urea (DMPU), NMP, or the like, and is applied to the substrate by art-known methods such as spin or spray coating or doctor blading. The solution uniquely has high solids content (e.g. 40-50%) which leads to enhanced planarization.

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The second step of the process involves heating the polyamic ester to an elevated temperature to both chain extend and imidize the polyamic ester. Preferably, the composition is heated in the presence of a base such as an amine or Bronsted base. The base catalyzes the imidization enabling a lower initial cure temperature e.g., less than 200°C. Suitably, the base is an organic amine. The amine will preferably have a high boiling point and is removable by heating upon completion of the reaction. A suitable base is N-methyldiethanolamine. Other suitable bases will be known to those skilled in the art such as disclosed in U.S. Patent 5,206,117, the disclosure of which is incorporated herein by reference for all purposes.

Referring to Fig. 3, the third step of the process involves lithographically patterning the layer 10 of dielectric composition to form trenches 12 (depressions) in the layer of composition. The trenches 12 shown in Fig. 3 extend to the substrate 2 and to the metallic studs 8. Lithographic patterning generally involves (i) coating the layer 10 of dielectric composition with a positive or negative photoresist such as those marketed by Shipley or Hoechst Celanese (AZ photoresist); (ii) imagewise exposing (through a mask) the photoresist to radiation such as electromagnetic, e.g., UV or deep UV; (iii) developing the image in the resist, e.g., with suitable basic developer; and (iv) transferring the image through the layer 10 of dielectric composition to the substrate 2 with a suitable transfer technique such as reactive ion beam etching

(RIE). Suitable lithographic patterning techniques are well known to those skilled in the art such as disclosed in Thompson et al., "Introduction to Microlithography" (1994), the disclosure of which is incorporated herein by reference.

Referring to Fig. 4, in the fourth step of the process for forming an integrated circuit of the present invention, a metallic film 14 is deposited onto the patterned dielectric layer 10. Preferred metallic materials include copper, tungsten, and aluminum. The metal is suitably deposited onto the patterned dielectric layer by art-known techniques such as chemical vapor deposition (CVD), plasma-enhanced CVD, electro and electroless deposition, sputtering, or the like.

Referring to Fig. 5, the last step of the process involves removal of excess metallic material (e.g., planarizing the metallic film 14) so that film 14 is generally level with the patterned dielectric layer 10. Planarization can be accomplished using chemical/mechanical polishing or selective wet or dry etching. Suitable chemical/mechanical polishing is known to those skilled in the art.

Referring to Figs. 6-8, there is shown an alternative embodiment of the process of the present invention for making an integrated circuit devices. The first step of the process in this embodiment involves depositing a metallic film 16 onto a substrate 18. Substrate 18 is also provided with vertical metallic

studs 20. Referring to Fig. 7, in the second step of the process, the metallic film is lithographically patterned through a mask to form trenches 22. Referring to Fig. 8, in the third step of the process, a layer 24 of polyamic ester of the present invention is deposited onto the patterned metallic film 16. In the last step of the process, the polyamic ester is heated to imidize the polyamic ester. Optionally, the dielectric layer may then be planarized for subsequent process in a multilayer integrated circuit.

The following examples are detailed descriptions of the present invention. The detailed preparations fall within the scope of, and serve to exemplify, the more generally described methods set forth above. The examples are presented for illustrative purposes only, and are not intended as a restriction on the scope of the invention.

Example 1 **Synthesis of Trimethoxysilane end capped Poly(Amic Ethyl Ester)**

meta-Diethylpyromellitate diacyl chloride (PMDA)
1,1-Bis(4-aminophenyl)-1-phenyl-2,2,2-trifluoroethane (3FDA)

A three-neck flask equipped with an overhead stirrer, nitrogen inlet and addition funnel was charged with 9.48 mmol (3.2456 g) 3FDA, 1.04 mmol (0.2218 g) aminophenyltrimethoxysilane, 25 mmol (2 g) pyridine, and 50 mL distilled NMP. The system was continuously maintained under a nitrogen purge. The reaction mixture was cooled to 0°C. The PMDA diethylester

diacychloride (10 mmol, 3.4716 g) was dissolved in ~100 mL of methylene chloride and quantitatively transferred to the addition funnel. The methylene chloride solution was added dropwise to the reaction mixture. After the addition was complete, the polymerization was allowed to proceed overnight at room temperature. The poly(amic ethyl ester) oligomers were isolated by coagulation in methanol, filtered and dried in a vacuum oven at 60°C (Mn=10,000).

Example 2 Film Formation

The poly(amic ethyl ester) oligomer from Example 1 was dissolved in NMP. A clear solution was formed with a solids content of 45 wt. %. The solution was subsequently cast by spin coating onto glass plates to form films from 1 to 10 microns thick. The imidization was accomplished by heating the polymer films for 1 hr. each at 200°C, 300°C and 400°C under N_2 atmosphere. The cured polyimide films were subsequently cooled slowly to room temperature. The cured polyimide were crack free, exhibited a dielectric constant of about 3.0 at 80°C temperature, thermal stress of about 45 Mpa, and a thermal expansion coefficient at 450°C of 75 x 10^{-6}.

Although this invention has been described with respect to specific embodiments, the details thereof are not to be construed as limitations for it will be apparent that various embodiments, changes, and modifications may be

resorted to without departing from the spirit and scope thereof, and it is understood that such equivalent embodiments are intended to be included within the scope of this invention.

What is claimed is:

1. An integrated circuit device comprising:

(a) a substrate;

(b) metallic circuit lines positioned on the substrate; and

(c) dielectric composition positioned contiguous to the circuit lines, the composition comprising imidized polyamic ester terminated with $(RO)_m(R'')_nSiR'$-, where R and R′ are independently a hydrocarbyl group; R″ is hydrido or hydrocarbyl group; m is 1, 2 or 3 and n+m=3, the dielectric composition having a thermal expansion coefficient of less than 1000×10^{-6}.

2. The device of claim 1 wherein the polyamic ester is terminated with a tri-C_{1-10} alkoxysilyl C_{1-10} alkyl group or tri C_{1-10} alkoxysilylaryl group.

3. The device of claim 2 wherein the polyamic ester comprises a diamine selected from 9,9′-bis (4-aminophenyl) fluorene, 4,4′ oxydianiline and 1,1-bis (4-aminophenyl)-1-phenyl-2,2,2-trifluoroethane, and a diester diacid halide selected from diC_{1-6} alkyl dichloro pyromellitate, diC_{1-6} alkyl dichlorooxydiphthalate and diC_{1-6} alkyl dichlorobiphenyl-tetracarboxylate.

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4. The device of claim 2 wherein the dielectric composition has a dielectric constant of less than 3.0.

5. A process for forming an integrated circuit comprising:

(a) positioning on a substrate a layer of dielectric composition comprising polyamic ester terminated with $(RO)_m(R'')_nSiR'$-, where R and R′ are independently a hydrocarbyl group; R″ is hydrido or hydrocarbyl group; m is 1, 2 or 3 and n+m=3;

(b) heating the composition to imidize the polyamic ester, the imidized polyamic ester having a thermal expansion coefficient less than 1000×10^{-6};

(c) lithographically patterning the dielectric layer;

(d) depositing a metallic film onto the patterned dielectric layer; and

(e) planarizing the film to form the integrated circuit.

6. The process of claim 5 wherein the polyamic ester is terminated tri-C_{1-10} alkoxysilyl C_{1-10} alkyl group or tri C_{1-10} alkoxysilylaryl group.

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7. The process of claim 6 wherein the polyamic ester comprises a diamine selected from 9,9´-bis 4-(aminophenyl) fluorene, 4,4´ oxydianiline, and 1,1-bis (4-aminophenyl)-1-phenyl-2,2,2-trifluoroethane, and a diester diacid halide selected from diC_{1-6} alkyl dichloro pyromellitate, diC_{1-6} alkyl dichlorooxydiphthalate and diC_{1-6} alkyl dichlorobiphenyl-tetracarboxylate.

8. A process for forming an integrated circuit comprising:

(a) depositing a metallic film on a substrate;

(b) lithographically patterning the metallic film;

(c) depositing on the patterned metallic film a layer of a dielectric composition comprising polyamic ester terminated with $(RO)_m(R'')_nSiR'$-, where R and R´ are independently hydrocarbyl group; R" is hydrido or hydrocarbyl group; m is 1, 2 or 3 and n+m=3; and

(d) heating the composition to imidize the polyamic ester, the imidized polyamic ester having a thermal expansion coefficient less than 1000×10^{-6}.

9. The process of claim 8 wherein the polyamic ester is terminated with a tri-C_{1-6} alkoxysilyl C_{1-6} alkyl group or tri C_{1-10} alkoxysilylaryl group.

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10. The process of claim 9 wherein the polyamic ester comprises a diamine selected from 9,9´-bis (4-aminophenyl) fluorene, 4,4´ oxydianiline, and 1,1-bis (4-aminophenyl)-1-phenyl-2,2,2-trifluoroethane and a diester diacid halide selected from diC_{1-6} alkyl dichloro pyromellitate, diC_{1-6} alkyl dichlorooxydiphthalate and diC_{1-6} alkyl dichlorobiphenyl-tetracarboxylate.

11. A polyamic ester terminated with $(RO)_m(R'')_nSiR'$-, where R and R´ are independently C_{1-10} alkyl or phenyl; R" is hydrido, C_{1-10} alkyl or phenyl; m is 1, 2 or 3 and n+m=3.

12. The polyamic ester of claim 11 wherein the ester is terminated with tri-C_{1-10} alkoxysilyl C_{1-10} alkyl group or tri-C_{1-10} alkoxysilylaryl group.

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13. An integrated circuit packaging device for providing signal and power current to an integrated circuit chip comprising:

(i) a substrate having electrical conductor for connection to a circuit board,

(ii) a plurality of alternating electrically insulating and conducting layers positioned on the substrate wherein at least one of the layers comprises imidized polyamic ester terminated with $(RO)_m(R'')_nSiR'$-, where R and R' are independently a hydrocarbyl group; R" is hydrido or hydrocarbyl group; m is 1, 2 or 3 and n+m=3, the imidized polyamic ester having a thermal expansion coefficient of less than 1000×10^{-6}, and

(iii) a plurality of vias for electrically interconnecting electrical conductor, conducting layers and the integrated circuit chip.

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14. The device of claim 13 wherein the polyamic ester is terminated with a tri-C_{1-10} alkoxysilyl C_{1-10} alkyl group or tri C_{1-10} alkoxysilylaryl group.

15. The device of claim 14 wherein the polyamic ester comprises a diamine selected from 9,9'-bis (4-aminophenyl) fluorene, 4,4' oxydianiline and 1,1-bis (4-aminophenyl)-1-phenyl-2,2,2-trifluoroethane, and a diester diacid chloride selected from diC_{1-6} alkyl dichloro pyromellitate, diC_{1-6} alkyl dichlorooxydiphthalate and diC_{1-6} alkyl dichlorobiphenyl-tetracarboxylate.

DIELECTRIC COMPOSITION AND INTEGRATED CIRCUIT DEVICE

ABSTRACT

The invention relates to an improved dielectric composition and an integrated circuit device comprising (i) a substrate (2), (ii) metallic circuit lines (4) positioned on the substrate (2), and (iii) the improved dielectric material (6) positioned on the circuit lines (4). The dielectric material comprises imidized polyamic ester preferably terminated with an alkoxysilyl alkyl group.

Fig. 1

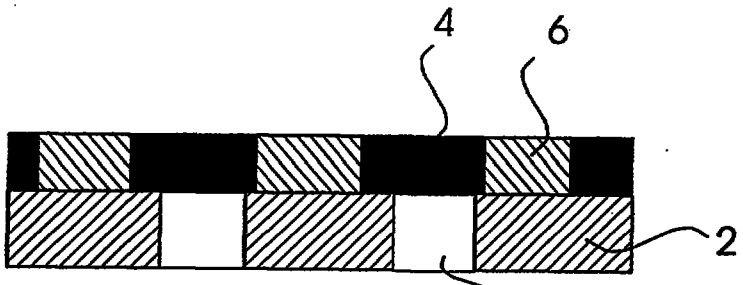


FIG. 1

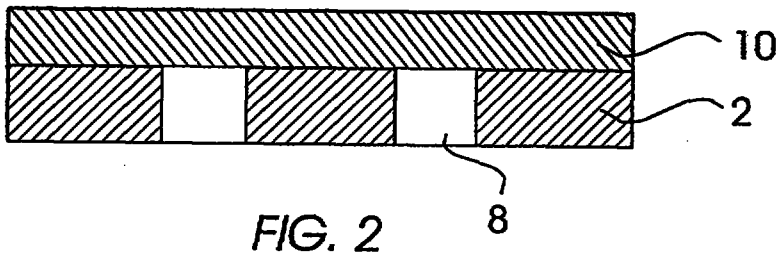


FIG. 2

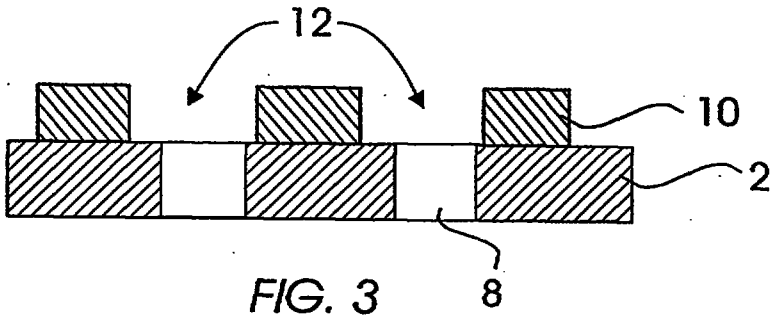


FIG. 3

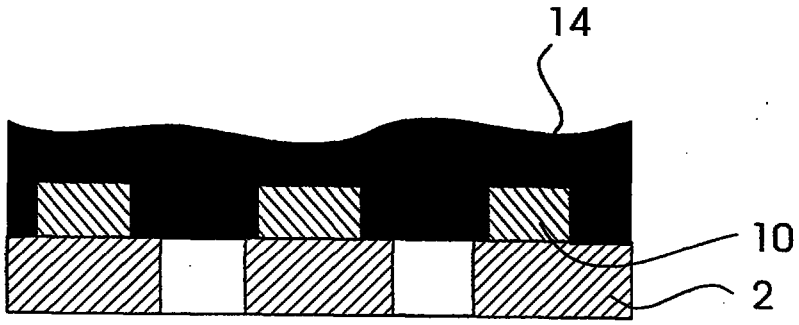


FIG. 4

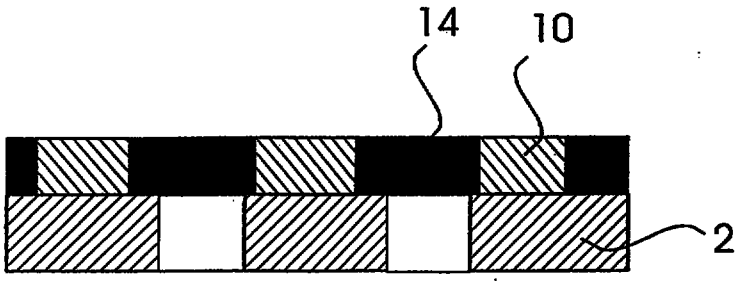


FIG. 5

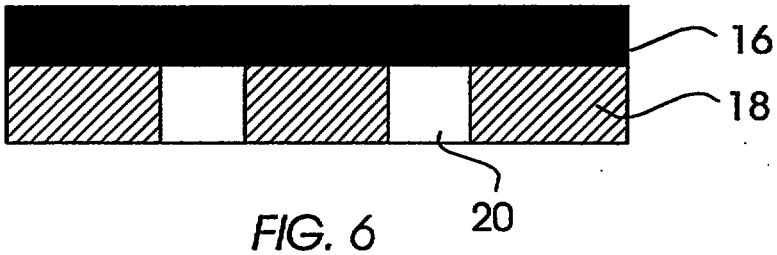


FIG. 6

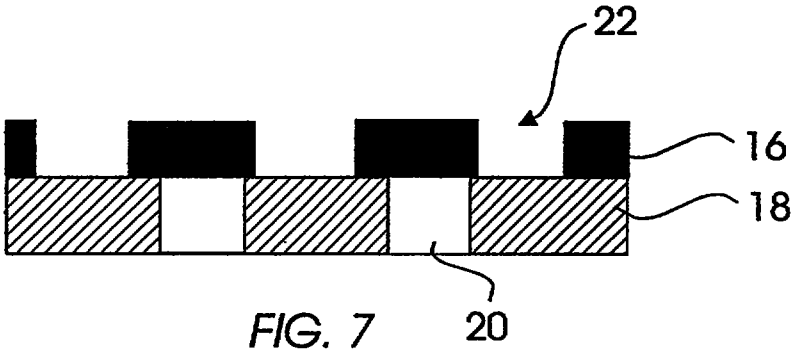


FIG. 7

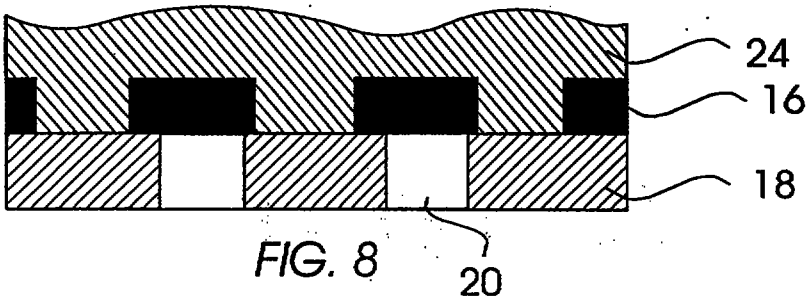


FIG. 8

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circuit linewidth, and also to decrease the dielectric constant of the interposed dielectric material to enable closer spacing of circuit lines without increase in crosstalk and capacitive coupling. Polyimide has a dielectric constant of about 3.0 with mechanical and thermal properties to withstand present processing operations and thermal cycling associated with semiconductor manufacturing. However, it is desired that dielectric materials for future integrated circuit devices exhibit a lower dielectric constant (e.g., <3.0) than exhibited by polyimide and have improved mechanical and thermal properties.

It is therefore an object of the present invention to provide an improved integrated circuit device comprising an improved dielectric material.

Other objects and advantages will be apparent from the following disclosure.

SUMMARY OF THE INVENTION

According to a first embodiment of this invention, there is provided an integrated circuit device comprising: (a) a substrate; (b) metallic circuit lines positioned on the substrate; and (c) dielectric composition positioned contiguous to the circuit lines, the composition comprising imidized polyamic ester terminated with $(RO)_m(R")_nSiR'$-, where R and R´ are independently a hydrocarbyl group; R" is hydrogen or hydrocarbyl group; m is 1, 2 or 3 and n+m=3, the dielectric composition having a thermal expansion coefficient of less than 1000×10^{-6}.

According to a second embodiment of this invention, there is provided a process for forming an integrated circuit comprising: (a) positioning on a substrate a layer of dielectric composition comprising polyamic ester terminated with $(RO)_m(R")_nSiR'$-, where R and R´ are independently a hydrocarbyl group; R" is hydrogen or hydrocarbyl group; m is 1, 2 or 3 and n+m=3; (b) heating the composition to imidize the polyamic ester, the imidized polyamic ester having a thermal expansion coefficient less than 1000×10^{-6}; (c) lithographically patterning the dielectric layer; (d) depositing a metallic film onto the patterned dielectric layer; and (e) planarizing the film to form the integrated circuit.

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According to a third embodiment of this invention, there is provided a polyamic ester terminated with $(RO)_m(R")_nSiR'$-, where R and R´ are independently C_{1-10} alkyl or phenyl; R" is hydrogen, C_{1-10} alkyl or phenyl; m is 1, 2 or 3 and n+m=3.

The present invention also relates to an improved dielectric material comprising cured polyamic ester terminated preferably with a trialkoxysilylalkyl group. The present invention also relates to an integrated circuit device. In one embodiment the device comprises (i) a substrate, (ii) interconnecting metallic circuit lines positioned on the substrate, and (iii) the improved dielectric material positioned contiguous to the circuit lines (over and/or between the circuit lines).

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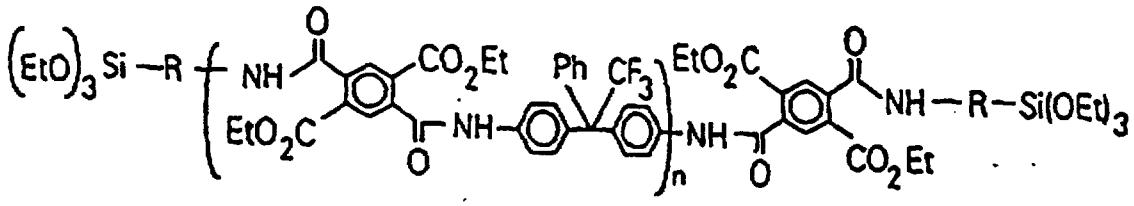
4,508,981, 4,628,411 and 4,811,082, the disclosures of which are incorporated herein by reference.

The key feature of the present invention is the dielectric material which is positioned over, around and/or between the circuit lines. In multilevel integrated circuit devices, the dielectric material can be often planarized to function as a substrate for the formation of the next layer of circuit lines. The dielectric material typically comprises an imidized polyamic ester terminated i (end group) with $(RO)_m(R'')_nSiR'$-, where , m is 1, 2 or 3; m+n=3; R and R′ are hydrocarbyl groups and R" is hydrido or a hydrocarbyl group. The end group is preferably a mono, di or tri C_{1-6} alkoxysilyl C_{1-6} alkyl or aryl group (e.g., phenylene, benzylene, napthylene or anthracenylene) group. As used herein, hydrocarbyl group means hydrocarbon based group (mono or difunctional) having a carbon atom attached to the remainder of the molecule and having predominantly hydrocarbon character. Hydrocarbyl groups include the following:

(1) Hydrocarbon groups; that is, aliphatic, (e.g., C_1-C_{10} alkyl or alkenyl and C_{5-10} cycloalkyl or cycloalkenyl), aromatic, aliphatic substituted aromatic, aromatic-substituted aliphatic and the like. Such groups are known to those skilled in the art; examples include methyl (methylene for difunctional hydrocarbyl group) ethyl, butyl, hexyl, octyl, decyl, dodecyl, tetradecyl,

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molecular weight (Mn) of about 5,000 to 20,000 g/mol. A suitable alkoxysilylalkyl end capped polyamic ester has the structure:



wherein R is phenyl or C_{1-6} alkyl and the polyamic ester substituent is ethyl.

The polyamic ester can be isolated and purified if desired. The polyamic ester solution has a high solids content (e.g., > 40-50 wt. %) with a low viscosity. The polyamic ester can be disposed on a substrate as a film by standard art-known techniques.

The dielectric composition is formed by curing the polyamic ester. The polyamic ester typically has a high imidization temperature of greater than 375°C. To cure the composition, the composition is typically heated to an elevated temperature directly or in a stepwise fashion (e.g., 200°C for 2 hrs. to cause chain extension and then ramped up to 400°C and held for 2 hrs.) to cause complete imidization of the polyamic ester and cross condensation of the silyl reactive groups.

The dielectric composition of the present invention typically has a dielectric constant less than 3.2, preferably less than 3.0, and more preferably less than 2.8 at 80°C. The dielectric composition typically has a low thermal expansion coefficient at elevated temperatures (e.g., less than 1000 x 10^{-6} [i.e., 1000 ppm] at 450°C preferably less than 500 x 10^{-6}; more preferably less than 100 x 10^{-6}) to

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avoid film cracking during subsequent thermal process steps. The composition has enhanced mechanical and polishing characteristics and enhanced isotropic optical and dielectric properties. The composition typically also has thermal stress of less than 100 MPa, preferably less than 50 MPa. Further, the dielectric composition has mechanical properties that resist cracking and enable it to be chemically/mechanically planarized to facilitate lithographic formation of additional circuit levels in multilevel integrated circuit devices. The dielectric composition has increased breakdown voltage, enhanced toughness, and increased crack resistance, even in high ambient humidity with a thick film. The dielectric composition is optically clear and adheres well to the substrate. The dielectric composition undergoes minimal shrinkage during heating (e.g., less than 10%).

The present invention also relates to processes for manufacturing the integrated circuit device. Referring to Fig. 2, the first step of one process embodiment involves disposing on a substrate 2 a layer 10 of the dielectric composition of the present invention comprising trialkoxysilylalkyl end-capped polyamic ester. The substrate 2 is shown with vertical metallic studs 8. The polyamic ester is dissolved in a suitable solvent such as dimethyl propylene urea (DMPU), NMP, or the like, and is applied to the substrate by art-known methods such as spin or spray coating or doctor blading. The solution uniquely has high solids content (e.g. 40-50%) which leads to enhanced planarization.

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What is claimed is:

1. An integrated circuit device comprising:

(a) a substrate;

(b) metallic circuit lines positioned on the substrate; and

(c) dielectric composition positioned contiguous to the circuit lines, the composition comprising imidized polyamic ester terminated with $(RO)_m(R")_nSiR'$-, where R and R' are independently a hydrocarbyl group; R" is hydrogen or a hydrocarbyl group; m is 1, 2 or 3 and n+m=3, the dielectric composition having a thermal expansion coefficient of less than 1000×10^{-6}.

2. The device of claim 1 wherein the polyamic ester is terminated with a tri-C_{1-10} alkoxysilyl C_{1-10} alkyl group or tri C_{1-10} alkoxysilylaryl group.

3. The device of claim 2 wherein the polyamic ester comprises a diamine selected from 9,9'-bis (4-aminophenyl) fluorene, 4,4' oxydianiline and 1,1-bis (4-aminophenyl)-1-phenyl-2,2,2-trifluoroethane, and a diester diacid halide selected from diC_{1-6} alkyl dichloro pyromellitate, diC_{1-6} alkyl dichlorooxydiphthalate and diC_{1-6} alkyl dichlorobiphenyl-tetracarboxylate.

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4. The device of claim 2 wherein the dielectric composition has a dielectric constant of less than 3.0.

5. A process for forming an integrated circuit comprising:

(a) positioning on a substrate a layer of dielectric composition comprising polyamic ester terminated with $(RO)_m(R'')_nSiR'$-, where R and R′ are independently a hydrocarbyl group; R″ is hydrogen or hydrocarbyl group; m is 1, 2 or 3 and n+m=3;

(b) heating the composition to imidize the polyamic ester, the imidized polyamic ester having a thermal expansion coefficient less than 1000×10^{-6};

(c) lithographically patterning the dielectric layer;

(d) depositing a metallic film onto the patterned dielectric layer; and

(e) planarizing the film to form the integrated circuit.

6. The process of claim 5 wherein the polyamic ester is terminated tri-C_{1-10} alkoxysilyl C_{1-10} alkyl group or tri C_{1-10} alkoxysilylaryl group.

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7. The process of claim 6 wherein the polyamic ester comprises a diamine selected from 9,9′-bis 4-(aminophenyl) fluorene, 4,4′ oxydianiline, and 1,1-bis (4-aminophenyl)-1-phenyl-2,2,2-trifluoroethane, and a diester diacid halide selected from diC_{1-6} alkyl dichloro pyromellitate, diC_{1-6} alkyl dichlorooxydiphthalate and diC_{1-6} alkyl dichlorobiphenyl-tetracarboxylate.

8. A process for forming an integrated circuit comprising:

(a) depositing a metallic film on a substrate;

(b) lithographically patterning the metallic film;

(c) depositing on the patterned metallic film a layer of a dielectric composition comprising polyamic ester terminated with $(RO)_m(R'')_nSiR'$-, where R and R′ are independently hydrocarbyl group; R" is hydrogen or hydrocarbyl group; m is 1, 2 or 3 and n+m=3; and

(d) heating the composition to imidize the polyamic ester, the imidized polyamic ester having a thermal expansion coefficient less than 1000×10^{-6}.

9. The process of claim 8 wherein the polyamic ester is terminated with a tri-C_{1-6} alkoxysilyl C_{1-6} alkyl group or tri C_{1-10} alkoxysilylaryl group.

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10. The process of claim 9 wherein the polyamic ester comprises a diamine selected from 9,9´-bis (4-aminophenyl) fluorene, 4,4´ oxydianiline, and 1,1-bis (4-aminophenyl)-1-phenyl-2,2,2-trifluoroethane and a diester diacid halide selected from diC_{1-6} alkyl dichloro pyromellitate, diC_{1-6} alkyl dichlorooxydiphthalate and diC_{1-6} alkyl dichlorobiphenyl-tetracarboxylate.

11. A polyamic ester terminated with $(RO)_m(R'')_nSiR'$-, where R and R´ are independently C_{1-10} alkyl or phenyl; R" is hydrogen, C_{1-10} alkyl or phenyl; m is 1, 2 or 3 and n+m=3.

12. The polyamic ester of claim 11 wherein the ester is terminated with tri-C_{1-10} alkoxysilyl C_{1-10} alkyl group or tri-C_{1-10} alkoxysilylaryl group.

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13. An integrated circuit packaging device for providing signal and power current to an integrated circuit chip comprising:

(i) a substrate having electrical conductor for connection to a circuit board,

(ii) a plurality of alternating electrically insulating and conducting layers positioned on the substrate wherein at least one of the layers comprises imidized polyamic ester terminated with $(RO)_m(R'')_nSiR'$-, where R and R' are independently a hydrocarbyl group; R" is hydrogen or hydrocarbyl group; m is 1, 2 or 3 and n+m=3, the imidized polyamic ester having a thermal expansion coefficient of less than 1000×10^{-6}, and

(iii) a plurality of vias for electrically interconnecting electrical conductor, conducting layers and the integrated circuit chip.